Cost-effectiveness of abdominal aortic aneurysm repair based on aneurysm size

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Objective: **To evaluate the cost-effectiveness of endovascular repair (EVAR) for small abdominal aortic aneurysms (AAA).**
Methods: **We developed a Markov model of a hypothetical 68-year-old cohort to determine the cost-effectiveness of early EVAR for "small" AAAs (4.0 cm-5.4 cm) compared with elective repair (open or endovascular) at the traditional cut-off of 5.5 cm. Repair options for 5.5-cm AAAs include both endovascular and open procedures. Probabilities were obtained from the literature. Costs reflected direct costs in 2007 dollars. Outcomes were reported as quality-adjusted life-years (QALYs).**
Results: **The model demonstrated that early EVAR for 4.0 cm-5.4 cm AAAs led to fewer QALYs at greater costs when compared with observational management with elective repair at 5.5 cm. Sensitivity analyses suggested that early EVAR of 4.6 cm-4.9 cm AAAs can be cost-effective if the long-term mortality rate after EVAR is ≤1.91% per year or if the quality of life after EVAR is improved. Likewise, if the quality of life before repair is low, EVAR for AAAs ≥4.6 cm may be cost-effective. With a >70% probability, observational management until AAA diameter is 5.5 cm will be the cost-effective option.**
Conclusions: **This analysis demonstrated that early EVAR for AAAs <5.5 cm is not likely to be cost-effective compared with elective repair at 5.5 cm. However, EVAR for small AAAs may become cost-effective when differences in quality of life and mortality are considered. (J Vasc Surg 2010;51:27-32.)**

Based on a study of open surgical repair and observational management, abdominal aortic aneurysms (AAAs) are considered for repair when they reach 5.5 cm in diameter.[1] Endovascular repair (EVAR) of AAAs <5.5 cm has demonstrated improved survival and lower rates of reintervention compared with EVAR of larger AAAs. These observations were also found when comparing AAAs <5.0 cm to AAAs ≥ 6.0 cm.[2] At our institution, subjects with AAAs >5.0 cm may be considered for EVAR. At least one ongoing randomized trial comparing EVAR for small AAAs and observational management is underway.[3]

The question of observational management or EVAR for AAAs <5.5 cm can also be addressed using current outcomes and Markov modeling. Thus, the goal of this report is to explore the cost-effectiveness of EVAR for AAAs <5.5 cm. Our model evaluates direct medical costs, morbidity, and mortality following EVAR for AAAs <5.5 cm and weighs these factors against observational management with elective repair at 5.5 cm.

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METHODS

Target population. The hypothetical cohort was 68 years old with an initial AAA diameter of 4.0 cm.

Model description. The health states were observational management, post-EVAR, post-open surgical repair, major stroke, dialysis, amputation, and death. Minor stroke, myocardial infarction (MI), bowel ischemia, infection, and pneumonia were temporary health states. The only transitions allowed from major stroke, dialysis, or amputation were to continue in the current state or death (Fig 1).

The cohort began in observational management, where aneurysm diameter grew with time. Annual aneurysm growth had a linear and a quadratic component.[4] The base case growth rate was about 2.7 mm per year. Once the AAA size exceeded a prespecified size (range, 4.0 cm-5.5 cm), a proportion of the cohort underwent EVAR. Those who were not suitable candidates for EVAR were returned to an observational management state, in which elective open surgical repair was performed once the AAA diameter reached 5.5 cm. Those who required a second AAA repair procedure could undergo either EVAR or open surgical repair and were transitioned to the appropriate health state.

Rupture risk for those in observational management varied with aneurysm size. Rupture risks for AAAs repaired by EVAR or open surgical repair were adapted from the literature.[5] Ruptured AAAs could be repaired by either EVAR or open surgical repair.

Perspective, boundaries, time horizon. The payer perspective was used and included only direct medical costs. The time horizon was the lifetime of the cohort.

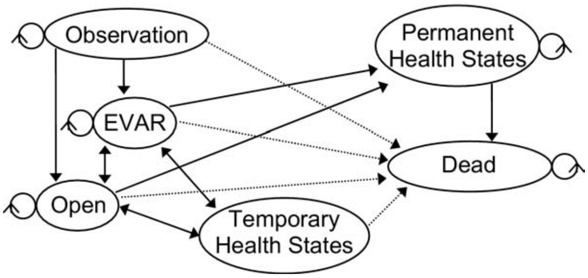


Fig 1. State transition diagram. Temporary states include minor stroke, MI, bowel ischemia, infection, vessel rupture, and endoleak. Those entering a temporary state are returned to the appropriate post-EVAR or post-open surgical repair. Permanent health states include dialysis, major stroke, and amputation. *EVAR,* Endovascular repair; *MI,* myocardial infarction.

Probability data. Perioperative, 30-day, adverse events were possible each time endovascular or open surgical repair was needed (Table I).[5] Long-term event probabilities were based on a variety of sources from the literature. The probability of reintervention after EVAR was the combined probability of repair for endoleak and repair for graft migration based on third-generation endografts.[6] An increased mortality rate for those with end-stage renal disease was incorporated into the model.[7,8]

Cost and utilization data. Costs represent direct medical costs in 2007 US dollars (Table I). Costs were obtained from publically available sources or from Medicare charges (changed to costs using cost-to-charge ratios).[9] References are listed in Table I. Where possible, nationally-based cost estimates, rather than costs from a single institution, were used to provide a broadly applicable analysis. Prices were adjusted using the Consumer's Price Index for medical care. Future costs and utilities were discounted at 3%.[10]

Utility data. Utility data, or preferences for a health state, were obtained from the literature (Table I). Quality-adjusted life-years (QALYs) are the utility of a given health state multiplied by the duration of the health state summed across the life span of the cohort. Perfect health and death represent health state preferences at 1.0 and 0, respectively. Infection and pneumonia were assumed to affect quality of life for 6 months.[11]

Analysis. EVAR for AAAs 4.0 cm to 5.5 cm was considered the intervention branch. The comparator was observational management of all AAAs until 5.5 cm, at which to point the aneurysm was repaired by EVAR or open surgical repair. The goal of the analysis was to determine the benefits of repair of AAA at diameters between 4.0 cm and 5.5 cm. Deterministic sensitivity analyses were two-way sensitivity analyses with the parameter of interest and AAA size varying from 4.0 cm to 5.5 cm. The willingness to pay was \$100,000/QALY, a threshold above which interventions were deemed too expensive. Willingness to pay is a tool assigning an economic value to 1 year of perfect health. These deterministic sensitivity analyses changed individual parameters, one at a time, over a range of AAA sizes. In reality, costs, utilities, and probabilities vary simultaneously. A probabilistic sensitivity analysis was conducted using 1,000 random samples of all parameters to assess second-order uncertainty within the model (see Table I for the list of variables and distributions).

RESULTS

Base case analysis. Early EVAR of 5.0-cm AAAs produced 0.05 fewer QALYs at an increased cost of \$3000 (Table II). The same trend, less quality of life at a greater cost, was found for early EVAR of AAAs as small as 4.0 cm. Thus, EVAR of AAAs smaller than 5.5 cm is not cost-effective.

Deterministic sensitivity analyses. We tested the parameters in the model over a range of values. All of the sensitivity analyses were conducted as two-way analyses with the variable of interest and AAA size cut-offs. The willingness to pay was \$100,000/QALY. In general, open surgical repair was more cost-effective than EVAR. When ≤5% of the cohort were candidates for EVAR, early EVAR was cost-effective starting at 4.6 cm. If the mortality rate after EVAR was ≤1.91% per year (age-adjusted to 68 years), EVAR of AAAs between 4.9 cm and 5.5 cm became cost-effective. When the rupture rate for 5-cm to 6-cm AAAs was ≥13.4% per year, EVAR for AAA diameters starting at 5.2 cm was cost-effective. Increasing the linear or quadratic component for AAA expansion suggested that cost-effective EVAR repair of rapidly expanding AAAs began at 5.2 cm.

We also tested the assumptions about costs and utilities. Worsening quality of life with an AAA favored repair at smaller diameters (Fig 2A, at and below the line). When the long-term utility after EVAR (beyond the first year) improved to ≥0.89, repair of AAAs 4.6 cm or larger was cost-effective (Fig 2B, at and above the line). Repair of 4.3-cm AAAs would be justified if EVAR returned the subject to near-perfect health (≥0.99). None of the assumptions about the cost parameters influenced the model.

Probabilistic sensitivity analysis. A probabilistic sensitivity analysis was used to determine the probability that either the choice to repair AAAs <5.5 cm or observe until 5.5 cm is beneficial at different economic values for 1 year of optimal health. The parameter estimates for costs, quality of life, and probabilities of adverse events were sampled simultaneously (Fig 3). Diameters of small AAAs for EVAR ranged from 4.0 cm to 5.4 cm. With a willingness to pay of \$50,000/QALY, observation until an AAA size of 5.5 cm has a 79% probability of being the cost-effective choice. Observational management has a 72% probability of being cost-effective when the willingness-to-pay is \$100,000/QALY.

DISCUSSION

This cost-effective analysis shows that EVAR for AAAs <5.5 cm in diameter results in higher direct medical costs for fewer QALYs gained. Also, with ≥72% probability, observational management is the welfare-enhancing choice

Table I. Base case probabilities for transitions to health states or adverse events, costs (2007 dollars), and utilities incorporated into the model

	Base case	*Range*	*Distribution*	*References*
Parameter				
Aneurysm size, initial (cm)	4.0	3.5-5.5	Uniform	
Linear expansion coefficient	0.26	0.24-0.28	Normal	4
Quadratic expansion coefficient	0.011	0.003-0.02	Normal	4
Age, initial (years)	68	60-75	Uniform	
Threshold for repair (cm)		4.1-5.5	Triangular	
Probabilities				
Aneurysm does not grow	0.064	0-0.3	Beta	4
Infection, case fatality	0.24	0-0.75	Beta	20
MI, case fatality	0.024	0-0.1	Beta	21
MI, per year after repair	0.012	0-0.05	Beta	22
Repair EVAR	0.4	0-1	Triangular	23
Rupture, fatal, outside hospital	0.4	0.16-0.59	Triangular	24, 25
Rupture, % repaired by EVAR	0.43	0-1	Triangular	23
Rupture, fatal, EVAR	0.19	0-0.5	Beta	23
Rupture, fatal, open	0.38	0-0.5	Beta	26, 27
Rupture, 4-5 cm	0.01	0-0.095	Beta	13, 28
Rupture, 5-6 cm	0.063	0-0.24	Beta	13, 28
Rupture, 6-7 cm	0.097	0-0.36	Beta	13, 29
Rupture, 7-8 cm	0.28	0-0.75	Beta	13, 29
Rupture, 8 cm	0.33	0-0.9	Beta	13
Stroke, per year after repair	0.002	0-0.01	Beta	30
Stroke, % minor	0.264	0-0.5	Triangular	31
Stroke, major, case fatality	0.13	0-0.2	Beta	32-34
EVAR 30-day				
Amputation	0.0004	0-0.01	Beta	5
Bowel ischemia	0.010	0-0.1	Beta	5
Dialysis	0.004	0-0.02	Beta	5
Infection	0.0001	0-0.01	Beta	5
MI	0.068	0-0.25	Beta	5
Mortality	0.012	0-0.1	Beta	5, 35, 36
Pneumonia	0.089	0-0.45	Beta	5
Stroke	0.026	0-0.2	Beta	5
Long-term, per year				
Endoleak/reintervention	0.059	0-0.3	Beta	6
Repair for this is EVAR	0.62	0-1	Triangular	
Infection	0.0056	0-0.03	Beta	20
Mortality, excess	0.029	0-0.06	Beta	12
Rupture	0.005	0-0.05	Beta	5
Open surgical repair 30-day				
Amputation	0.0013	0-0.01	Beta	5
Bowel ischemia	0.021	0-0.1	Beta	5
Dialysis	0.005	0-0.02	Beta	5
Infection	0.0009	0-0.01	Beta	5
MI	0.09	0-0.25	Beta	5
Mortality	0.047	0-0.25	Beta	5, 35, 36
Pneumonia	0.16	0-0.45	Beta	5
Stroke	0.01	0-0.2	Beta	5
Long-term, per year				
Infection	0.0019	0-0.03	Beta	20
Mortality, excess	0.0293	0-0.06	Beta	12
Rupture	0.0012	0-0.05	Beta	6
Costs (2007 $)				
AAA endovascular repair	21,000	10,000-50,000	Triangular	37
AAA open repair	19,700	10,000-50,000	Triangular	37
Amputation, long-term	20,900	9,500-38,000	Triangular	38, 39
Dialysis, renal failure	89,500	37,750-155,000	Triangular	40, 41
EVAR, follow-up	1750	250-4000	Triangular	
Infection, first 2 years	9700	4,150-16,600	Triangular	42
Infection, after 2 years	14,200	6,100-24,400	Triangular	42
Major stroke, hospitalization	15,000	6,000-26,000	Triangular	42-47
Major stroke, 1st year	58,800	40,000-80,000	Triangular	43, 48-50
Major stroke, 2nd year	30,600	15,000-45,000	Triangular	43, 48-50

Table I. Continued

	Base case	*Range*	*Distribution*	*References*
MI	15,600	6,700-26,800	Triangular	42
MI, fatal	19,250	8,250-33,000	Triangular	42
Minor stroke	15,000	6,000-26,000	Triangular	42-47
Open repair, follow-up	180	0-400	Triangular	
Observational management	90	0-200	Triangular	
Utilities				
Observation with AAA	0.75	0.5-1.0	Triangular	14-16
EVAR, 1st year	0.7	0.3-1.0	Triangular	14-16
EVAR, 2+ years	0.71	0.3-1.0	Triangular	14-16
Open	0.71	0.3-1.0	Triangular	14-16
Amputation	0.65	0.4-0.9	Triangular	51-55
MI	0.79	0.5-1.0	Triangular	56, 57
Minor stroke	0.73	0.5-1.0	Triangular	58-60
Major stroke	0.21	0-0.5	Triangular	58-61
Pulmonary	0.91	0.8-1.0	Triangular	62
Renal	0.64	0.5-0.75	Triangular	63-65
Bowel ischemia	0.64	0.5-0.75	Triangular	63-65
Discount rate	3%	0-8		9

AAA, Abdominal aortic aneurysm; *EVAR,* endovascular aneurysm repair; *MI,* myocardial infarction.

Table II. Base case analysis

	Cost (2007 $)	*Incremental cost*	*QALY*	*Incremental QALY*	*ICER ($/QALY)*
Repair at 5 cm	30,900		7.11		
Repair at 5.5 cm	27,900	(−) 3,000	7.16	(−) 0.05	Dominant

QALY, Quality-adjusted life-years.
Values were obtained using a Markov cohort of 1,000 hypothetical individuals.

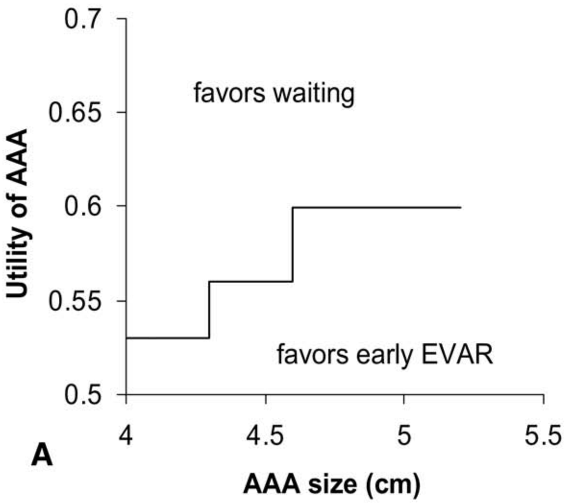
over a range of economic values. Thus, the model supports the current algorithm of observational management until the aneurysm reached 5.5 cm in diameter.

Contrary to this report, two retrospective studies suggest that EVAR of "small" AAAs is associated with better outcomes.[2,12] Our model is based on analysis of a larger Medicare data set (>22,000 records),[5] a large registry database (>6700 records),[6] and a randomized trial.[13] Our analysis also delineates circumstances in which EVAR would be a suitable option for AAAs <5.5 cm. EVAR of 4.9-cm AAAs becomes cost-effective when the long-term mortality rate after EVAR ≤1.91% per year (almost to the level of the age-adjusted US population) while the surgical mortality rate is held at 4.5% (age-adjusted to 68 years). EVAR of 5.2-cm AAAs would be suitable for either rapidly expanding AAAs (≥0.28 cm/year, base case = 0.27 cm/year) or when the rupture risk for 5-6 cm AAAs is ≥13.4% per year. This 13.4% rupture risk may be roughly double the actual risk but is within the upper limit of estimated risks for AAAs of this size (3%-15%).[14]

Quality of life before and after repair also influenced the cost-effectiveness of EVAR for small AAAs. Improvements in quality of life with EVAR increase the number of QALYs generated by the model and thus create a potentially cost-effective intervention. A poorer quality of life prior to repair (due to anxiety over the AAA, for example), leads to greater quality of life gains after repair. Higher utilities after EVAR, ≥0.89, also generate more QALYs. Restoring quality of life to ≥0.89 is improving one's health dramatically because the quality of life with an AAA is estimated at 0.75.[15-17] However, at the population level, quality of life changes with EVAR do not show drastic improvements.[15-17]

Our model is consistent with other cost-effectiveness analyses that show favorable health benefits for open surgical repair compared with EVAR.[18,19] Additionally, the UK-Small Aneurysm Trial demonstrated that early open surgical repair of AAAs ≥4.5 cm produced small quality of life gains at a minimal cost.[20] This is consistent with our model in which EVAR for smaller AAAs does not produce substantive health gains.

One limitation to this study is that the model does not incorporate individually measured cost and utility values. Nonetheless, this analysis includes point estimates from a large Medicare population.[5] This analysis does not include indirect medical costs that may differ following open surgical repair or EVAR. Lost productivity and other expenses are of value to society as a whole. Finally, we included absolute aneurysm size based on different growth rates but not the influences of other health conditions such as family history or chronic obstructive pulmonary disease (COPD). We addressed family history, other comorbidities and anatomic features with a broad category—suitable for EVAR



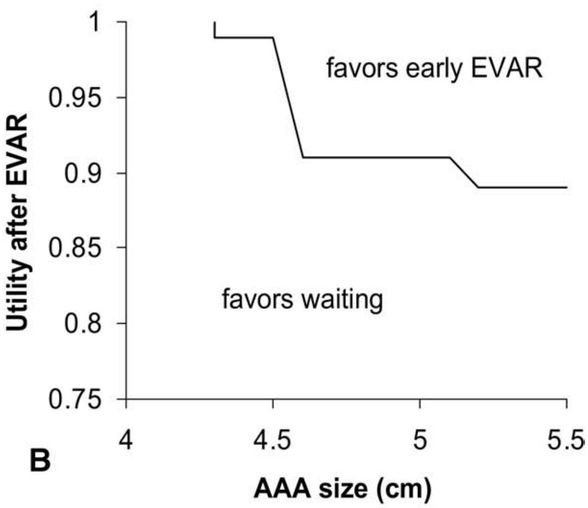


Fig 2. Deterministic two-way sensitivity analyses show the relationship between health state preferences of living with an AAA (A) or after EVAR repair (B) and the AAA diameter for EVAR repair. EVAR of small AAAs would be cost-effective, with a willingness to pay of $100,000/QALY, when perceived health with an AAA is poor or when health is greatly improved after repair. *AAA,* Abdominal aortic aneurysm; *EVAR,* endovascular repair; *QALY,* quality-adjusted life-years.

or not. Advantages to this study include the incorporation of many 30-day adverse events, long-term rupture, and options for reintervention when necessary.

CONCLUSIONS

This cost-effectiveness analysis supports the current practice of observational management for AAAs <5.5 cm in diameter. Simultaneously sampling all of the parameters supports this conclusion; there is at least a 72% likelihood that observational management until an AAA diameter of 5.5 cm is beneficial over a range of economic values QALY.

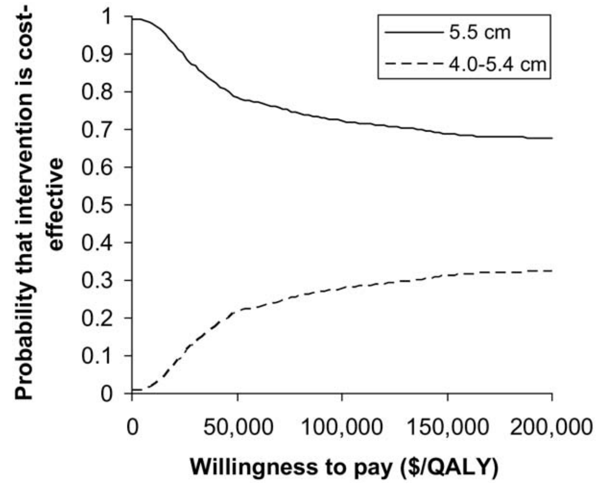


Fig 3. Probabilistic sensitivity analysis. Simultaneously sampling over a range of costs, health state preferences and probabilities demonstrated that observational management of AAAs until 5.5 cm, compared with EVAR between 4.0 cm and 5.4 cm, would be the cost-effective treatment modality about 70% of the time. *AAA,* Abdominal aortic aneurysm; *EVAR,* endovascular repair.

AUTHOR CONTRIBUTIONS

Conception and design: KY, NA, MJ, DG, MS, KI
Analysis and interpretation: KY, MS
Data collection: KY, NA
Writing the article: KY
Critical revision of the article: KY, MS, KI
Final approval of the article: KY, NA, MJ, DG, MS, KI
Statistical analysis: KY
Obtained funding: N/A
Overall responsibility: KY

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DISCUSSION

Dr Ruth Bush *(Temple, Tex)*. I congratulate Dr. Young and the coauthors on the presentation of cost-effectiveness of endovascular aneurysm repair. I also very much appreciate receiving the manuscript well ahead of this meeting. I have the following questions and a comment:

1. This model takes into account the cost of repair. However, as we all know, with endovascular aneurysm repair, the cost of lifelong surveillance and secondary intervention does add to the overall cost. Is there a way to include this in the model? And do you think it matters, Dr. Young?
2. Some suggest that women should undergo intervention at smaller aneurysm diameters due to differences in vessel size, and we will hear about that later on today. Is there any way to incorporate gender into this model?
3. As we all hear, almost on a daily basis, and I believe President Obama is meeting with the AMA next week, health care reform is near the top or at the top of the current administration's agenda. How do you see your conclusions fitting in or influencing that agenda?

And my last thing to say is a comment. I believe your data set is robust, your statistical analysis is exact and on target, and I would encourage you, after reviewing the manuscript, that the purpose, the introduction, and the discussion should fit the methods and the results. I found those very good. Again, I appreciate the opportunity to review this paper.

Dr Young. Gender is included inherently in the model based on the probabilities of rupture and growth.

In terms of surveillance, costs for this after endovascular and after open repair are assumed to be equal and thus wouldn't contribute to the incremental cost-effectiveness ratio. If one requires more surveillance than the other, it is possible it could change the incremental cost-effectiveness ratio, likely making EVAR more expensive. This scenario would still favor waiting because open repair is more cost-effective. None of the cost assumptions in my model affected the results, but it is possible.

With a public health hat, we certainly need more information from surgeons as to what the best size to intervene is, what are the risks, and what are the benefits. This model and the information we have collected can certainly be refined as more data become available to help address these questions.

Dr Benjamin Starnes *(Seattle, Wash)*. You've looked at the cost-effectiveness using a Markov model of analysis and quality-adjusted life-years based on size of the aneurysm. What are your thoughts – and this is just asking you what your personal opinion is – on a comparison of cost-effectiveness of screening for abdominal aortic aneurysms versus the cost-effectiveness of treating a ruptured aneurysm? Can you comment on that?

Dr Young. No. I'm not familiar with the cost-effectiveness for screening of abdominal aortic aneurysms.